stitute a factor, which cannot fail to have an important bearing in all general questions, such as the growth of the cell wall, the conduction of food, the ascent of water, the process of fertilisation, the penetration of fungi into their host, the process of secretion, and the transmission of the impulses which determine growth and movement of plant organs.

Concerning certain of these problems, I should like to make a few concluding remarks.

As to the passage of water from the root hair to the vessel, the presence of connecting threads in the cells of root tissue makes it possible to imagine that the ordinary laws of osmosis may be profoundly modified, and that the filaments which establish protoplasmic continuity may conduct stimuli, leading, for instance, to a difference in reaction of the proximal and distal halves of any given cell. Similarly, it is conceivable that a definite polarity is established, which helps to determine the direction of the flow. As to the larger question of rapid water movement, although this is neither the time nor the place to enter into theory, yet I cannot refrain from remarking that it is not impossible that the threads, doubtless present in large quantities in dead vessels, may, if they suffer mucilaginous change, have some bearing on the question, *e.g.*, by assisting to sustain the water at any given level or attracting water in the immediate environment. In any case, I am strongly of opinion that the part played by mucilage and the force of hydration have not as yet received sufficient attention.

As to movements generally, I am still unable to accept Pfeffer's view of the subsidiary part played by the protoplasm in connexion with turgidity,* and I am still of opinion that the ectoplasm is the master factor which determines the condition of the cell. The present research demonstrates among other things that there are fixed points in the ectoplasm, and this may have some bearing on the possibility of establishing the periodic or sudden contractions and dilatations which I believe are associated with turgescence, and of which such a phenomenon as the effusion of water from the cells of a stimulated *Mimosa* pulvinus is but an abnormal instance.

"On the Viscosity of Hydrogen as affected by Moisture." By Lord Rayleigh, F.R.S. Received September 8, 1897.

In Sir W. Crookes's important work upon the viscosity of gases† the case of hydrogen was found to present peculiar difficulty. "With each improvement in purification and drying I have obtained

* Gardiner, 'Roy. Soc. Proc.,' vol. 43, 1887.

† 'Phil. Trans.,' 1881, p. 387.

a lower value for hydrogen, and have consequently diminished the number expressing the ratio of the viscosity of hydrogen to that of air. In 1876 I found the ratio to be 0·508. In 1877 I reduced this ratio to 0·462. Last year, with improved apparatus, I obtained the ratio 0·458, and I have now got it as low as 0·4439" (p. 425). The difficulty was attributed to moisture. Thus (p. 422): "After working at the subject for more than a year, it was discovered that the discrepancy arose from a trace of water obstinately held by the hydrogen—an impurity which behaved as I explain farther on in the case of air and water vapour."

When occupied in 1888 with the density of hydrogen, I thought that viscosity might serve as a useful test of purity, and I set up an apparatus somewhat on the lines of Sir W. Crookes. A light mirror, 18 mm. in diameter, was hung by a fine fibre (of quartz I believe) about 60 cm. long. A small attached magnet gave the means of starting the vibrations whose subsidence was to be observed. The viscosity chamber was of glass, and carried tubes sealed to it above and below. The window, through which the light passed to and fro, was of thick plate glass cemented to a ground face. This arrangement has great optical advantages, and though unsuitable for experiments involving high exhaustions, appeared to be satisfactory for the purpose in hand, viz., the comparison of various samples of hydrogen at atmospheric pressure. The Töppler pump, as well as the gas generating apparatus and purifying tubes, were connected by sealing. But I was not able to establish any sensible differences among the various samples of hydrogen experimented upon at that time.

In view of the importance of the question, I have lately resumed these experiments. If hydrogen, carefully prepared and desiccated in the ordinary way, is liable to possess a viscosity of 10 per cent. in excess, a similar uncertainty in less degree may affect the density. I must confess that I was sceptical as to the large effect attributed to water vapour in gas which had passed over phosphoric anhydride. Sir W. Crookes himself described an experiment (p. 428) from which it appeared that a residue of water vapour in his apparatus indicated the viscosity due to hydrogen, and, without deciding between them, he offered two alternative explanations. Either the viscosity of water vapour is really the same as that of hydrogen, or under the action of the falling mercury in the Sprengel pump decomposition occurred with absorption of oxygen, so that the residual gas was actually hydrogen. It does not appear that the latter explanation can be accepted, at any rate as regards the earlier stages of the exhaustion, when a rapid current of aqueous vapour must set in the direction of the pump; but if we adopt the former, how comes it that small traces of water vapour have so much effect upon the viscosity of hydrogen?

It is a fact, as was found many years ago by Kundt and Warburg* (and as I have confirmed), that the viscosity of aqueous vapour is but little greater than that of hydrogen. The numbers (relatively to air) given by them are 0·5256 and 0·488. It is difficult to believe that small traces of a foreign gas having a 6 per cent. greater viscosity could produce an effect reaching to 10 per cent.

In the recent experiments the hydrogen was prepared from amalgamated zinc and sulphuric acid in a closed generator constituting in fact a Smee cell, and it could be liberated at any desired rate by closing the circuit externally through a wire resistance. The generating vessel was so arranged as to admit of exhaustion, and the materials did not need to be removed during the whole course of the experiments. The gas entered the viscosity chamber from below, and could be made to pass out above through the upper tube (which served also to contain the fibre) into the pump head of the Töppler. By suitable taps the viscosity chamber could be isolated, when observations were to be commenced.

The vibrations were started by a kind of galvanometer coil in connection (through a key) with a Leclanché cell. As a sample set of observations the following relating to hydrogen at atmospheric pressure and at 58° F., which had been purified by passage over fragments of sulphur and solid soda (without phosphoric anhydride), may be given:—

Observations on June 7, 1897.

—	65·4	—	—	—
423·7	88·9	358·3	2·554	—
401·3	110·0	312·4	2·495	0·059
381·5	128·9	271·5	2·434	0 061
364·4	144·1	235·5	2 372	0·062
349·7	158·6	205·6	2·313	0·059
336·8	169·8	178·2	2·251	0·062
325·7	180·6	155·9	2·193	0·058
315·7	189·8	135·1	2·131	0·062
307·2	197·8	117·4	2·070	0·061
300·0	204·6	102·2	2·009	0·061
293·7	210·6	89·1	1·950	0·059
287·8	—	77 2	1·888	0·062

Mean log. dec. = 0·0604.

The two first columns contain the actually observed elongations upon the two sides. They require no correction, since the scale was bent to a circular arc centred at the mirror. The third column

* 'Pogg. Ann.,' 1875, vol. 155, p. 547.

gives the actual arcs of vibration, the fourth their (common) logarithms, and the fifth the differences of these, which should be constant. The mean logarithmic decrement can be obtained from the first and last arcs only, but the intermediate values are useful as a check. The time of (complete) vibration was determined occasionally. It was constant, whether hydrogen or air occupied the chamber, at 26·2 seconds.

The observations extended themselves over two months, and it would be tedious to give the results in any detail. One of the points to which I attached importance was a comparison between hydrogen as it issued from the generator without any desiccation whatever and hydrogen carefully dried by passage through a long tube packed with phosphoric anhydride. The difference proved itself to be comparatively trifling. For the wet hydrogen there were obtained on May 10, 11, such log. decs. as 0·0594, 0·0590, 0·0591, or as a mean 0·0592. The dried hydrogen, on the other hand, gave 0·0588, 0·0586, 0·0584, 0·0590 on various repetitions with renewed supplies of gas, or as a mean 0·0587, about 1 per cent. smaller than for the wet hydrogen. It appeared that the dry hydrogen might stand for several days in the viscosity chamber without alteration of logarithmic decrement. It should be mentioned that the apparatus was set up underground, and that the changes of temperature were usually small enough to be disregarded.

In the next experiments the phosphoric tube was replaced by others containing sulphur (with the view of removing mercury vapour) and solid soda. Numbers were obtained on different days such as 0·0591, 0·0586, 0·0588, 0·0587, mean 0·0588, showing that the desiccation by soda was practically as efficient as that by phosphoric anhydride.

At this stage the apparatus was rearranged. As shown by observations upon air (at 10 cm. residual pressure), the logarithmic decrements were increased, probably owing to a slight displacement of the mirror relatively to the containing walls of the chamber. The sulphur and soda tubes were retained, but with the addition of one of hard glass containing turnings of magnesium. Before the magnesium was heated the mean number for hydrogen (always at atmospheric pressure) was 0·0600. The heating of the magnesium to redness, which it was supposed might remove residual water, had the effect of *increasing* the viscosity of the gas, especially at first.* After a few operations the logarithmic decrement from gas which had passed over the hot magnesium seemed to settle itself at 0·0606. When the magnesium was allowed to remain cold, fresh fillings gave again 0·0602, 0·0601, 0·0598, mean 0·0600. Dried air at 10 cm.

* The glass was somewhat attacked, and it is supposed that silicon compounds may have contaminated the hydrogen.

residual pressure gave 0·01114, 0·01122, 0·01118, 0·01126, 0·01120, mean 0·01120.

In the next experiments a phosphoric tube was added about 60 cm. long and closely packed with fresh material. The viscosity appeared to be slightly increased, but hardly more than would be accounted for by an accidental rise of temperature. The mean uncorrected number may be taken as 0·0603.

The evidence from these experiments tends to show that residual moisture is without appreciable influence upon the viscosity of hydrogen; so much so that, were there no other evidence, this conclusion would appear to me to be sufficiently established. It remains barely possible that the best desiccation to which I could attain was still inadequate, and that absolutely dry hydrogen would exhibit a less viscosity. It must be admitted that an apparatus containing cemented joints and greased stop-cocks is in some respects at a disadvantage. Moreover, it should be noticed that the ratio 0·0600 : 0·1120, viz. 0·536, for the viscosities of hydrogen and air is decidedly higher than that (0·500) deduced by Sir G. Stokes from Crookes's observations. According to the theory of the former, a fair comparison may be made by taking, as above, the logarithmic decrements for hydrogen at atmospheric pressure, and for air at a pressure of 10 cm. of mercury. I may mention that moderate rarefactions, down say to a residual pressure of 5 cm., had no influence on the logarithmic decrement observed with hydrogen.

I am not able to explain the discrepancy in the ratios thus exhibited. A viscous quality in the suspension, leading to a subsidence of vibrations independent of the gaseous atmosphere, would tend to diminish the apparent differences between various kinds of gas, but I can hardly regard this cause as operative in my experiments. For actual comparisons of widely differing viscosities I should prefer an apparatus designed on Maxwell's principle, in which the gas subjected to shearing should form a comparatively thin layer bounded on one side by a moving plane and on the other by a fixed plane.